The Technical Program of the Factory Automation Systems Division 1992

Howard M. Bloom
Larry W. Masters

U.S. DEPARTMENT Of COMMERCE
Technology Administration
National Institute of Standards and Technology
Manufacturing Engineering Laboratory
Factory Automation Systems Division
Gaithersburg, MD 20899

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U.S. DEPARTMENT OF COMMERCE
Barbara Hackman Franklin, Secretary

TECHNOLOGY ADMINISTRATION
Robert M. White, Under Secretary for Technology

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
John W. Lyons, Director

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INTRODUCTION

This report describes the 1992 technical program of the Factory Automation Systems Division (FASD), one of four technical divisions in the Manufacturing Engineering Laboratory (MEL), Of the National Institute of Standards and Technology (NIST). The report is divided into four sections: Introduction, Division Overview, Description of Programs, and the Factory Automation Systems Division: An Engineering Research Paradigm.

MEL supports the U.S. mechanical manufacturing industry through research and measurement services that are oriented toward a modern automated environment. The programs of the Laboratory are organized into five areas: Automated Manufacturing, Precision Engineering, Robotics, Manufacturing Data Interface Standards, and Support for Manufacturing Technology Transfer.

The work of FASD contributes primarily to the automated manufacturing and data interface standards areas. The Automated Manufacturing efforts lead to the development of methods and systems for design, process planning, scheduling, production management and inspection. The Manufacturing Data Interfaces Standards thrust, which is expected to experience the greatest growth in the next decade of all Laboratory programs, develops the national standards for a "paperless" manufacturing and logistic support system. Data interface standards are an essential element in the U.S. industry's efforts to draw upon the principles of concurrent engineering, a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support [1]. Central to these efforts is the development of an international "Standard for the Exchange of Product Model Data" (STEP). The U.S. national effort is called PDES, "Product Data Exchange using STEP." In April 1991, the National Critical Technologies Panel, appointed by the Director of the Office of Science and Technology, published a report on critical technologies [2]. In the critical manufacturing process technology area called "systems management technologies," the report included a discussion of the importance of PDES.

DIVISION OVERVIEW

MISSION AND FUNCTION

The mission of FASD is to provide a focus for national research and standards efforts related to information systems for manufacturing. In recent years, information technology and information systems have become increasingly important in the manufacturing enterprise. Improved information systems are key elements in refining current manufacturing methods and in

creating new technologies to develop products, reduce production costs, shorten commercialization lead times, and raise overall product quality.

In carrying out its mission, the Division contributes to the strength of manufacturing in the United States and to the ability of the United States to remain competitive in world markets.

A major objective of the Division is to provide leadership in the development of national and international standards relating to information technology and manufacturing systems to meet U.S. industry needs for the twenty-first century (see Figure 1). The work of the Division is based on the principle that this leadership must be founded on experience in implementing and testing new information technologies and engineering concepts. Such experience is used by Division staff to develop and promote appropriate standards and technologies (and the engineering disciplines needed to support them), particularly for manufacturing interface standards and product data exchange standards for automated manufacturing systems.

TECHNICAL PROGRAMS

The scope of the Division's programs is the application of information technology to a multi-enterprise environment. More specifically, the Division's staff members apply their expertise in information technology and their knowledge of manufacturing to promote multi-enterprise concurrent engineering in the manufacturing of discrete parts. The work can be divided into four programs, as shown in Figure 2:

- Design Methods,
- Product Data Sharing,
- Systems Integration, and
- Life Cycle Applications.

The Design Methods Program develops, through the use of computer-shared data bases and knowledge, the ability to include information about all stages of a product's life cycle in the design process. The Product Data Sharing Program provides leadership and a testing-based foundation for the rapid and complete development of the STEP specification. The Systems Integration Program addresses issues associated with the integration of information and communication services across a manufacturing enterprise. The Life Cycle Applications Program works to implement prototype applications to test proposed standards, concepts and frameworks.

The four Division programs are at different stages in their growth toward the size and strength intended for them to meet the goals of their missions. Currently, the Product Data Sharing Program is significantly larger than the other programs.

Typical outputs for the Division include: draft specifications for future standards, journal papers describing research results, prototype

software systems that demonstrate proof-of-concept, test methodologies for supporting the implementation of standards, and testbeds for use by NIST, industry, and academia.

The funding distribution among the Division's technical programs is shown in Figure 3. Support from agencies outside (0A - Other Agency) of NIST represents about 73% of the total budget (about $5.6M of the Division's total $7.7M budget). The remainder of the funding is appropriated to NIST as part of the Department of Commerce budget and is termed STRS (Scientific and Technical Research Support).

The Division actively seeks guidance on national issues and research needs from many sources throughout U.S.-based industry. Typical sources include manufacturers, National Research Council (NRC) and National Science Foundation (NSF) committees and publications, MEL Assessment Panel, visits to and by industry, professional/trade associations and their publications, Government agencies, university representatives, guest workers, industrial consortia, industry review boards, university consortia, standards committees, and sponsors. The information and guidance provided by the industry is vital as the Division develops strategies for responding to industry needs and, at the same time, responding to needs of the specific sponsors of its research.

To help ensure that the work carried out by the Division is, to the extent possible, consistent with its programmatic roadmap, the following criteria are used in helping select industrial and/or sponsor needs to be addressed by the Division:

- The work is consistent with the FASD/MEL/NIST mission
- The need is verifiable to industry
- The results of the work provide potential technological and/or economic impact to the U.S.
- An achievable objective can be stated or, for high-risk tasks, the potential payoff is large and
- Resources (funds) are likely to be available.

(See figures 1, 2, and 3)

DIVISION STAFF

The Division is organized into four technical groups: Production Management Systems, Product Data Engineering, Integrated Systems, and Machine Intelligence. There are two projects managed from within the Division office: the IGES/PDES/STEP Administrative Office (IPO) and the CALS/PDES Project Management Office. The Division organization chart is shown in Figure 4. IGES and CALS are acronyms for Initial Graphic Exchange Specification and Computer-aided Acquisition and Logistics Support, respectively.

Permanent Staff:		Special Staff:	
Management	7	Summer Students	18
Professional	36	Guest Researchers	3
Technical Support	5	Research Associates	2
Secretarial Support	8		
Total	23		
	Total	56	

The functional statements of the four Groups are as follows:

Production Management Systems-*Supports the Division's efforts to provide a national focus for research and standards efforts related to information systems for manufacturing. Group activities are centered around a subset of automation systems which support production engineering and manufacturing engineering. Examples of the kinds of systems that PMSG addresses within production engineering include control architectures, cell controllers, and production scheduling; within manufacturing engineering, the systems include process planning and off-line programming. The Group performs research and development work to advance the state of the art for manufacturing systems and to identify open interfaces that will support interoperability, when these systems are used by different vendors. The Group actively participates in U.S. and international activities to develop standards for integrated manufacturing systems.*

Product Data Engineering-*Pursues research into the technologies required to develop a product data model that can serve as a national/international standard. Such technologies include product data modeling, data access and storage including object-oriented data management systems, software tools (i.e. compilers, translators, and parsers in an integrated software engineering environment) and validation testing procedures. Focus of the work is in the use of these technologies to develop and implement STEP, as well as to provide for conformance testing of STEP-based implementations. The facilities of the National PDES Testbed are used to examine implementations of PDES in order to better understand how to augment the standard*

and perform validation and testing on emerging versions. The Group also studies new techniques for the representation of standards documents and activities through the use of such technologies as hypertext and hypermedia.

Integrated Systems-*Advances knowledge and understanding of information technology (computers, software, and networks) applied to advanced manufacturing. There are both research and applied components to the mission. The research includes technology transfer through standards development and work in distributed systems, configuration management, and enterprise integration. Experience gained from research is applied to management of our own distributed network of computing resources in the Division and to support an onllne information service for the PDES project.*

Machine Intelligence-*Contributes to the Division's research programs on Product Data Sharing and Life Cycle Applications. The Group carries out work in the areas of metal powder production, apparel product data exchange, inspection software performance testing, and inspection methods with an increasingly focused effort in mechanical tolerancing and related issues. The Group actively participates in national and international standards activities.*

(See figure 4)

MAJOR CUSTOMERS

The Division's primary customer is U.S.-based industry, including manufacturers, suppliers, and distributors. Industry interacts with the Division staff both directly and indirectly through a variety of standards organizations, consortia, industrial enterprises, other government agencies, and universities. The Division cooperates with these organizations in mutually beneficial partnerships, and contributes to their work by developing testing methodologies, providing testbeds, developing integration and architecture concepts, and implementing feasibility demonstrations. As shown in the diagram in Figure 5, the Division fulfills the ideal role of NIST in providing the metrological and consensual basis for standards, technologies and products.

(See figure 5)

INTERACTIONS WITH OTHER ORGANIZATIONS

STANDARDS ORGANIZATIONS:

Manufacturing and product-related standards have become internationally important in trade agreements. A June 1991 meeting between U.S. and European Community representatives led to the following joint communique: "International standardization and openness of conformity assessment were an indispensable means of eliminating or avoiding the creation of technical barriers to the international trade." Recently, both Government and industry have realized the importance of accelerating and participating in the development of standards because standards impact the ability of U.S. industry to be globally competitive. The Office of Science and Technology Policy stated in a report published in September 1990 that the Administration's strategy to implement U.S. technology policy includes encouraging "increased U.S. participation in multi-lateral international standardization efforts through the standards activities of the National Institute of Standards and Technology." Accordingly, a key customer of the Division has become the U.S. standards community. Division staff members serve in chair positions and on technical development committees, and they provide support for secretariats.

The following is a list of national and international standards organizations with which the Division interacts, along with the names of staff members who serve in key capacities.

National

AAMA (American Apparel Manufacturers Association) CIM Standards Committee (T. Hopp; T.Lee)

ANSI (American National Standards Institute)
B89:Dimensional Metrology
B89.3.2:Measurement Methods (T. Hopp; S. Feng; M. Algeo)
B89.4.10: Coordinate Measurement Machine Software (T. Hopp; M. Algeo)
Electronic Product Data Harmonization Organization
ClMSB (CIM Standards Board)

X3:Information Processing Systems
X3T.2:Data Interchange (E. Barkmeyer)
X3H2.1: Remote Database Access
X3J16:Programming Language C+ +
Y14:Standards for Drawings and Drafting Practices
Y14.5.1: Mathematics of Dimensions and Tolerances
(T. Hopp; M. Algeo; S. Feng)

lGES/PDES Organization: Product Data Standards and Technology
Chair: B. Conroy

Editor: J. Wellington
Exec. Asst.: M. Andrews
Application Validation Methodology
Architecture, Engineering and Construction
Composites
Dictionary/Methodology
Drafting (A. Barnard)
Electrical Applications
Finite Element Analysis
Form Features
Geometry
Implementation Specifications (Chair: J. Fowler)
Implementors
Interoperability Testing Methodology
Manufacturing Technology (S. Ray)
Materials
Mechanical Product Definition
PDES Development Methods
PDES Visual Presentation
Product Life Cycle Support
Product Structure
Qualification and Integration
Recommended Practices
Software Products
Standard Parts
Technical Publications
Test Case Design
Testing Methodologies Tolerance (Chair: J. Crusey; S. Feng)

International

150 (International Organization for Standardization)
TC1O:Technical Drawings
TC1O/SC1: Basic Conventions
TC184: Industrial Automation Systems and Integration
TC184/SC4: Industrial Data and Global Manufacturing Programming Languages (Chair: B. Smith; J. Wellington)
TC184/SC4/WG2:Parts Libraries
TC184/SC4/WG3:Product Modeling (J. Crusey)
TC184/SC4/WG4:Qualification and Integration (M. Mitchell)
TC184/SC4/WG5:STEP Development Methods
TC184/SC4IWG6:Conformance Testing Procedures (M. Mitchell)
TC184/SC4/WG7:Implementation Specifications
TCI84/SC4/WG8:Manufacturing Management Data (S. Ray; K. Senehi)
Joint WG9: Electrical/Electronics Applications
TC184/SC5: Architecture and Communications
TC184/SC5/WG1:Reference Models

IS0/IEC (International Organization for

Standardization/International Electrotechnical Commission) Joint Technical Committee 1

JTC1/SC22/WG11: Language Binding Techniques (Editor: E. Barkmeyer)

CONSORTIA:

To compete with European and Japanese industries, U.S. companies have increasingly joined together to form research and technology consortia. The Division has been working with consortia in the development of pre-competitive technology and also for accelerating the development of standards. Consortia accept NIST as a neutral government agency, as a testbed for technology transfer into the companies, and for development of test methodology for controlling the quality of the output. The Division interacts with the following consortia.

Name	**Program/Project**
PDES, Inc.	National PDES Testbed
AAMA	PDES for Apparel Industry
Powdered Metals Const.	Metal Powder Processing
CAM-I	Systems Integration
MCC	Enterprise Integration
Sematech	Systems Integration
European Strategic Prog. for R&D in Information Technology (ESPRIT)	US/EC Collaboration on Manufacturing System Research

INDUSTRY (Users of Manufacturing Technology):

Large manufacturing companies continue to view the Division as a means of technology transfer of new research into their own laboratories for further development. In addition, the Division uses the interaction to better understand U.S. manufacturing needs. The Division has joint research efforts with the following companies.

Name	**Program/Project**
Boeing	Manufacturing Systems
GM/EDS	IGES/PDES/STEP Administrator
IBM	National PDES Testbed
GM	Manufacturing Systems Integration
Industrial Technology Institute (lTl)	STEP Conformance Testing and Interorganizational Assessment for PDES Adoption

INDUSTRY (Producers of CIM Technology):

The Division has become a mechanism for demonstrating new technologies that are available from CIM (Computer Integrated Manufacturers) vendors. In addition, the prototype systems developed through the Division's testbeds are made available to vendors for future development of actual products. The following vendors are users of the Division's facilities.

Name	**Activity**
Control Data	Information modeling system software donation
D. Appleton Co.	Information modeling system software donation
DEC	VAX 8810 computer system, workstations, and software donation
Graphael	Object-oriented database software donation
HP	Workstation loan (expected)
IBM	Workstations and CAD software loan
ICAD	CAD software donation
ModaCAD	Apparel CAD software donation
Ontologic	Object-oriented data base software donation
Oracle	Relational database software donation
Prime/CV	CAD/CAM hardware and software donation
Pritsker	Scheduling and control software donation
Quantum Access	CD-ROM Retrieval Software donation
Savoir	Emulation of control systems software donation
Serviologic	Object-oriented database software donation
Versant	Object-oriented database management system and software donation (expected)

OTHER GOVERNMENT AGENCIES:

Most of the Division's funding is derived from technical and standards-related projects that are supported by other government agencies. NIST has a unique role in the standards arena that will continue to attract other government agencies as customers. Government agencies which support the Division's research are listed below.

Sponsor	**Project(s)**
Air Force/Mantech	Enterprise Integration Framework
Army/Rock Island Arsenal	Tool Management Specification
Defense Advanced Research Projects Agency (DARPA)	Manufacturing Research Testbed, Persistent Object Base Evaluation, National Process Planning Test bed
DoD/CALS	National PDES Testbed
DoD/Defense Logistics Agency (DLA)	PDES for Apparel Industry
U.S. Postal Service (USPS)	Automated Processing System

Navy/Mantech	AMRF Program: Manufacturing Systems Integration, Collaboration on Manufacturing Automation Protocol (MAP), Industrial Collaboration, CMM Software Performance, IMAR Intelligent Modules, Reverse Engineering Production Cell, STEP Conformance Testing and Interorganization Assessment

UNIVERSITIES:

The Division is developing a new role in its relationship with university researchers. Through the sponsorship of other government agencies such as DARPA and DLA, universities have been funded to work on critical problems relating to engineering design and manufacturing. The Division is helping to integrate the work and to transfer the results of the work among the participating universities. The outcome of this activity is more effective sharing and utilization of Government-sponsored university research results. The universities listed below are participating in joint research with the Division.

Sponsor/Project	**University**
DARPA/Manufacturing Research Testbed	Carnegie Mellon University, Cornell University, Purdue University, Rensselaer Polytechnic Institute, Stanford University, University of Utah
DARPA/Persistent Object Base Evaluation	Massachusetts Institute of Technology, University of Colorado, University of Oregon, University of Wisconsin, Carnegie Mellon University, University of Utah, Rensselaer Polytechnic Institute
DLA/PDES for Apparel Industry	Clemson University, Fashion Institute of Technology, Georgia Institute of Technology, North Carolina State University, University of Southwestern Louisiana
Navy Mantech/Intelligent Module	University of California at Los Angeles, University of Southern

California, Arizona State
University, California
Institute of Technology

Contract/System Integration University of Arizona

DESCRIPTION OF PROGRAMS

DESIGN METHODS PROGRAM

MISSION: *Develop, through the use of computer-shared databases and knowledge, the ability to include information about all stages of a product's life cycle in the design process*

OBJECTIVES/APPROACH:

A major objective is the development of the means to incorporate product knowledge (such as knowledge about the product's manufacture, maintenance and disposal) into the design system database, as well as the integration of appropriate computer representations of a product.

Design research is performed in the Engineering Design Laboratory. The laboratory is an integrated design and analysis environment for modeling the technical information needed to design and build complex mechanical systems. The Laboratory makes use of university-developed research tools and commercially available design and analysis tools. Both the development of the product models and the issues raised in integrating a diverse set of computer-based tools will help to identify interface problems, to evaluate the usefulness of STEP in the design process, and to contribute to standards development.

TECHNICAL THEMES:

- Formal methodologies for design
- Computer representation of in-progress designs, especially feature-based representations
- Design-oriented analysis and simulation tools
- Quality and cost models for design
- Common definition and methods for encoding and disseminating design knowledge
- Theory of tolerances

- Interfaces for integrating design tools
- Architecture for design-tool functionality

CURRENT STATUS:

The design program is currently very small but it is expected to grow in future years. At this time it is comprised of only two projects, which cannot address all the important technical themes within the scope of the design program. New projects are being sought and are anticipated.

REPRESENTATIVE RECENT ACCOMPLISHMENTS:

- Developed and installed mechanisms for remote execution of design tools over the Internet and for access to repositories of product data models in standard formats.
- Established a network with DARPA-funded university design/analysis research projects for the exchange of design, STEP, and analysis files.
- Demonstrated tools for using design knowledge to assess product performance by developing interfaces between a conceptual design tool and analysis tools.
- Developed and documented a model of the vibration isolation system of the NIST Molecular Measuring Machine (M^3).

REPRESENTATIVE PLANNED ACCOMPLISHMENTS:

- Provide ongoing technical consulting services to DARPA by participating in DARPA workshops, evaluating broad agency announcements, and performing proposal reviews and similar efforts.
- Install and evaluate commercial feature-based modeling systems to determine capabilities in future DARPA-sponsored programs.
- Organize and conduct a workshop on the use of STEP for design-related research programs with university principal investigators.
- Prepare background study on computer-aided factory engineering which identifies current efforts, critical issue areas, technical barriers, and opportunities for automated software tools.

MAJOR PROJECTS (Sponsor):

Manufacturing Research Testbed (DARPA/SISTO)
Evaluate software tools for integrating design and analysis; provide consultation to DARPA on sponsored research programs; facilitate the transfer of DARPA-sponsored research results to industry.

Computer-Aided Factory Engineering (STRS)
Develop a long range program which will (1) investigate critical issue areas pertaining to engineering factories in the U.S. and (2) identify and develop solutions for computer-aided factory engineering that will help reestablish national prominence in manufacturing.

STAFF: Professional 3

FACILITIES: Engineering Design Laboratory

IMPACT:

Including information about all stages of a product's life cycle in the design process expands the designer's role and improves efficiency in product development. Results of the evaluation of research design and analysis tools for integration of the design, analysis, and manufacturing stages of a product's life cycle will be used: (1) by DARPA to set programmatic goals for future work, and (2) by the PDES/STEP community to determine the design information required in the standard to support analysis, such as structural and thermal stress analysis.

LONG-TERM GOAL:

The long-term goal of the Design Methods program is an intelligent design workstation that demonstrates concurrent design processes using an integrated set of software tools, models, and knowledge data bases.

PRODUCT DATA SHARING PROGRAM

MISSION: *Provide technical leadership and a testing-based foundation for the rapid and complete development of the STEP specification.*

OBJECTIVES/APPROACH:

STEP is being developed as a neutral method and mechanism that can be used to completely represent product data throughout the life cycle of a product. The completeness of this representation makes it suitable not only for neutral file exchange, but also for implementing and sharing databases and for archiving. The Product Data Sharing Program focuses on the development of STEP, methods for testing the standard, and methods for implementing it in a shared-database environment. In addition, to help promote the achievement of STEP-based commercial systems, NIST is assisting in establishment of a long-range STEP development and deployment plan and a national testing network.

TECHNICAL THEMES:

- Extensions of STEP through application protocols
- Implementing STEP in applications-environments
- Verification, validation, and conformance testing methods
- Tool kits for supporting STEP development
- Extensions to information modeling and database technologies
- Harmonization among product and application standards

CURRENT STATUS:

The Product Data Sharing Program is the largest program in the Division. At present, it is funded primarily by the Department of Defense. Additional support from the Department of Commerce is anticipated, in accord with a Memorandum of Understanding between the Departments.

REPRESENTATIVE RECENT ACCOMPLISHMENTS:

- Defined a testing methodology for STEP Application Protocol validation and proposed it to the STEP community.
- Established and accepted the position of Chair of a new project within TC184/SC4/WG4 in order to establish the validation testing methodology for STEP within the standards-development process.

- Defined and published requirements and architecture for software systems to support the validation testing of STEP Application Protocols.
- Led a national effort to establish a standards committee to develop STEP extensions for the apparel industry.
- Led the national effort to define an initial specification of the STEP Data Access Interface (SDAI) and to utilize it in vendor-developed prototypes. The lessons learned in the development and demonstration of these prototypes are being used to ensure that the first version of the SDAI will be technically complete.
- Defined and published an architecture for a mechanical parts production system based on STEP.
- Contributed to the development and deployment of the National Initiative for Product Data Exchange.
- Served as the primary contributor to a document describing a high-level architecture for implementing a PDES/STEP data-sharing environment.
- Presented STEP requirements to the database research community and explored the development of mechanisms to provide for their active participation in the deployment of STEP.
- Published strategic and technical plans for STEP Application Protocol specification and validation and conformance testing.
- Published a document discussing issues and recommendations for an Application Protocol Framework.
- Released the first version of the C+ + STEP class library for working with EXPRESS structures.
- Published a document discussing issues and recommendations for STEP conformance testing.
- Published requirements for information model quality management.
- Developed an initial comprehensive training plan for expanding the pool of effective STEP standards participants.
- Led the development of the initial versions of the Model Qualifications Guidelines that are being used to ensure the quality-and consistency of STEP parts.

REPRESENTATIVE PLANNED ACCOMPLISHMENTS:

- Release a STEP editing tool, the DataProbe, for use by the STEP community. The second version of the C+ + STEP class library for working with EXPRESS structures will be included in this release.
- Sponsor a workshop to address the issues related to validation testing within the development of STEP.
- The STEP Data Access Interface and the STEP Tolerance Model will be technically completed and submitted for CD ballot.
- Release software tools designed to support the development of STEP-based applications that are consistent with Part 11, EXPRESS within STEP Release 1.0 specifications.
- Develop a memorandum of agreement to collaborate on the development of STEP conformance testing with representatives of the European Community.
- Research and document the relationship between conformance testing and STEP - qualification and integration (WG4) in particular, to validation testing of Application Protocols.
- Survey and recommend existing technologies and technical elements from other standards (i.e., test notation, testing laboratory/client procedures) that can be used in STEP conformance testing.
- Prototype, experiment and evaluate tools that could be used in STEP conformance testing.
- Develop a prototype application protocol for generating an apparel procurement specification.

MAJOR PROJECTS (Sponsor):

IGES/PDES/STEP Administration Office (STRS)
Support the development of STEP by chairing and operating the U.S. Secretariat for 150 Technical Committee 184, Subcommittee 4 and chairing the IGES/PDES Organization.

PDES for Apparel Industry (DoD/DLA)
Assist DoD to improve the productivity, quality control, and competitiveness of the U.S. apparel industry by helping to develop methods for product data exchange appropriate to the industry.

Interorganizational Assessment for PDES Adoption (Navy/Mantech)
To develop a prototype computer-based tool for assessing interorganizational readiness for using PDES, through a Cooperative Research and Development Agreement (CRDA) with ITI (Ann Arbor, MI).

National PDES Testbed (DoD/CALS and others)
Provide technical leadership for the development of the STEP standard by establishing (1) a testing program for validating the draft STEP specifications, (2) a STEP Mechanical Parts Production Cell for evaluating and demonstrating the use of STEP in an industrial environment, (3) a configuration control system for managing and making available STEP documents and software, and (4) a national Product Data Exchange Network in cooperation with the CALS Test Network.

The following projects are included:

- AP Framework and Methodology: Being carried out in NIST's Building and Fire Research Laboratory (BFRL)
- AP for Inspection Planning (STRS/NIST Director's Reserve)
- IPO/ISO Technical Support
- Configuration Management
- Testbed Readiness
- Validation Testing System
- Conformance Testing (Navy/Mantech) and
- STEP Implementation Tools.

STAFF:

Professional	20
Technical Support	3
Clerical Support	3
Guest Scientist	1
Research Associate	1

FACILITIES: Validation Testing Laboratory
STEP Information Service Facility
Apparel Design Research System

IMPACT:

The development of STEP, an essential element in the creation of a multi-enterprise, concurrent engineering environment, involves hundreds of technical experts around the world; it is one of the largest and most complex standards efforts ever. Major institutions that are involved formally in the development of STEP include: the 150 Subcommittee (TC184/SC4); the IGES/PDES Organization, the ANSI U.S. Technical Advisory Group to TC184/SC4; the PDES, Inc. industrial consortium, and NIST. NIST is involved in all aspects of the development of STEP, primarily as the leader in the development and implementation of testing procedures. The development of STEP fits into NIST's mission to develop standards for information technology and to develop tests to ensure that computer software and data conform to the standards. STEP must be based upon an accurate representation of data that is exchanged or shared during the various stages of a product's life cycle.

The NIST National PDES Testbed supports the goals of IPO and IS0 to establish an international standard that will support product data sharing. The National PDES Testbed was established at NIST in 1988 under U.S. Department of Defense Computer-aided Acquisition and Logistic Support (CALS) program funding. Standards which support product data sharing are recognized as a major building block in the CALS program. Under CALS sponsorship, the National PDES Testbed is supporting the development of product sharing technologies not only for the Department of Defense, but also for other agencies within the U.S. government and American industry. The staff of the National PDES Testbed are not only involved with 150 and IPO, but also actively participate in the program of PDES, Inc. NIST is a Government Associate in the PDES, Inc. industrial consortium.

A November 1990 Memorandum of Understanding (MOU) between the Department of Defense, Production and Logistics, and the Department of Commerce, Technology Administration, identifies PDES and STEP as integral to the common goal of accelerating the development and deployment of "technology that will result in higher quality, shorter time to production, and lower costs for both weapon systems and commercial products." Under the MOU action plan, the Department of Commerce is supporting CALS/PDES standards through research and development of relevant technologies, standards organization activities, technology transfer, information dissemination, and management and coordination of the National PDES Testbed.

In January 1992, the National Initiative for Product Data Exchange was initiated. The Division played an important part in forming the Initiative and is expected to participate in the program.

LONG-TERM GOAL:

The long term goal for the Product Data Sharing Program is a product data standard that defines all the data needed to cover the entire life cycle of a complex product such as a motorized vehicle. The standard will specify the application protocols against which life cycle applications can be tested. In addition, the standard will specify the shared database or knowledge base environment for implementing product data specifications.

SYSTEMS INTEGRATION PROGRAM

MISSION: *Address issues associated with the integration of information and communication services across a manufacturing enterprise.*

OBJECTIVES/APPROACH:

The mission of the Systems Integration Program will allow U.S. industry to develop and implement national and international standards that will enable the integration of services necessary to perform engineering- and manufacturing-related operations. The Program has three major activities:

- To participate in and promote collaborative efforts between national and international programs which are dedicated to the definition and development of frameworks, architectures and standards to achieve integration;

- To identify new technologies that can be used in Government-sponsored research efforts dedicated to integration-related issues and to promote the development of these technologies; and

- To facilitate the process of standards development by promoting the transfer of technology and research results among industrial, Government, academic and standards organizations to increase the productivity and competitiveness of U.S. industry.

The merging of standards for information technology, manufacturing data sharing, and product data-exchange standards, in which NIST plays a key role, will begin the process of developing a framework for integration of engineering- and manufacturing-related operations. Research within the Program covers both long- and short-term integration issues in critical technologies for Computer Integrated Manufacturing (CIM). The Systems Integration program provides an essential foundation for research to combine all levels of the manufacturing enterprise through networks and computers.

TECHNOLOGY THEMES:

- Information modeling of manufacturing management data
- Architecture design for production management environments
- Framework for enterprise integration
- Specifications for different views of an enterprise
- Harmonization of existing standards.

CURRENT STATUS:

The Systems Integration Program was established in 1990 with the creation of the Manufacturing Systems Integration (MSI) project. In 1991, the Enterprise Integration project was added to study issues at higher levels of a manufacturing enterprise. The Systems Integration Program also includes three additional projects which address integration- related technology themes. Each project is focused on integration issues at various levels of a manufacturing enterprise and address both long- and short-term technology and standards objectives. Key integration issues addressed in the Program include information integration, communication integration, and standards integration.

REPRESENTATIVE RECENT ACCOMPLISHMENTS:

- Established a collaborative R&D program with EC (European Community)/ESPRIT (European Strategic Programme for Research and Development in Information Technology) and organized two international workshops on Manufacturing Technologies with ESPRIT.

- Contributed to efforts to harmonize emerging standards for data access and new object information standards being undertaken by ANSI X3.H7.

- Designed an open system architecture for integrating production management and shop floor software applications, and demonstrated an initial working prototype integrated testbed utilizing real and emulated manufacturing equipment.

- Designed a production management information model and implemented a generic factory controller to utilize ALPS (A Language for Process Specification) to communicate process information across planning, scheduling and production control.

- Completed initial prototype of the integrated testbed, which included process planning, scheduling, shop control and factory configuration management software systems.

- Developed an emulation of a machining cell to test the MSI architecture and control entity interface specifications, and to test tool management concepts within machining cells.

- Participated in the review of the Air Force's Enterprise Integration Program (EIP).

REPRESENTATIVE PLANNED ACCOMPLISHMENTS:

- Continue to actively participate in the object-oriented database (OODB) development community to transfer engineering and manufacturing requirements to the OODB community.

- Continue to contribute to efforts to harmonize emerging standards for data access, such as SQL, SDAI, IRDS, and new object-information standards being undertaken by ANSI X3.H7.

- Establish an evaluation process for POB based on available requirements from manufacturing and engineering.

- Complete and document the unified production management information model, the configuration definition model, the configuration status model and the factory resource model.

- Implement and populate data bases conforming to the information models for process and production planning, facility, configuration, control entity and resources.

- Adapt the prototype scheduling system to conform to the interface specifications and integrate the scheduler into the MSI architecture.

- Integrate the Machining Cell Emulation System into the MSI architecture. The emulated cell will exhibit realistic system behavior that will enable testing and validation of the MSI architecture.

- Establish a CRDA with General Motors to develop software for achieving CIM.

- Integrate MSI scheduling and control systems into emulated workcell and test different production scenarios for multiple machines using planning data supplied by Rock Island Arsenal.

- Develop a software platform to examine various aspects of cell control with emphasis on scheduling and tool management, including tool monitoring and tool allocation strategies.

- Establish a lab for MAP (Manufacturing Automation Protocol) and TOP (Technical and Office Protocol) at NIST.

- Organize Third International Workshop on Manufacturing Technologies.

MAJOR PROJECTS (Sponsor):

Technology Evaluation of Persistent Object Bases for Engineering and Manufacturing Environments (DARPA)
To assist DARPA in a technology evaluation of persistent object bases and their applicability in a distributed, STEP-based manufacturing environment.

Manufacturing Systems Integration (MSI) (Navy/Mantech and STRS)
To develop a system architecture which incorporates an integrated production planning and control environment and to establish a testbed for production management architectures which integrate process planning, production planning and shop floor control.

Machining Cell Emulation System (MCES) (Navy/Mantech and STRS)
To develop a multi-platform emulation system for manufacturing cells to enable execution of the MSI process plans and production schedules.

MAP/TOP Laboratory Development (AMRF/STRS)
To establish a lab environment at NIST which is representative of the computing environment and associated communication systems in state-of-the-art manufacturing facilities.

Industrial Collaboration Project (AMRF/STRS)
To increase the number of candidates for Cooperative Research and Development Agreements (CRDAs) through establishment of a collaborative program between industrial sites and the Division. This project would provide additional opportunities for FASD staff to gain increased knowledge and understanding of the manufacturing environments of participating companies.

Enterprise Integration (El) (Air Force/Mantech and STRS)
To lead international activities aimed at defining and developing a framework and guidelines for applying information technology (computers, software, and networks) to improve industrial competitiveness.

STAFF:

Professional	9
Technical Support	2
Clerical Support	2
Guest Researchers	2

FACILITIES:

The facilities which support the Systems Integration Program include a wide range of computer hardware and software systems used for developing and demonstrating concept prototypes within the integrated testbed. The laboratory facilities for all supporting projects are contained within the Shops Building at NIST, and function as both development and demonstration environments. Additional facilities within the AMRF are used throughout the year for meetings and tours with visitors and sponsors.

LONG-TERM GOALS:

The long-term goals of the Systems Integration Program include:

1) the establishment of standard information models for manufacturing management data,
2) the incorporation of all relevant information and communication standards to demonstrate the use of standards to achieve integration,
3) the transfer of standards and new technology to the academic research community, other Government agencies and the American industry, and
4) the development of an international standard for enterprise integration.

LIFE CYCLE APPLICATIONS PROGRAM

MISSION: *Implement prototype applications to test proposed standards, concepts and frame works*

OBJECTIVES/APPROACH:

The mission of the Life Cycle Applications Program is the implementation of prototype applications of different processes in different manufacturing industries to test proposed standards, concepts and frameworks for shared database and "knowledge-base" technology. The applications are implemented in both laboratory and more realistic manufacturing environments. The results of such applications lead to further understanding and improvements in manufacturing-related standards and information technology methods. Through the development of applications, NIST collaborates with U.S. industry as well as other Government agencies to transfer and implement technology.

TECHNOLOGY THEMES:

- Testing general methodologies in specific applications
- Product-data-driven processing
- Methodologies for capturing and representing process data
- Applicability of standards to support manufacturing functions

CURRENT STATUS:

The scope and variety of projects in the Life Cycle Applications Program will be increased as opportunities to apply the Division's research and development results become available.

REPRESENTATIVE RECENT ACCOMPLISHMENTS:

- Demonstrated the utility of off-the-shelf multimedia technology to visualize the internal operations of software systems.
- Published draft standards for the assessment of coordinate measuring machine (CMM) software and for the mathematics of tolerances.
- Completed implementation of an algorithm testing system for coordinate measuring machines.
- Established engineering principles for using manufacturing process models to design the inspection process.

- Devised and implemented intelligent control strategies to achieve desired particle size distributions in a metal powder process.

- Completed and documented an open systems architecture for a tool management ºsystem at Rock Island Arsenal.

REPRESENTATIVE PLANNED ACCOMPLISHMENTS:

- Establish a fully functional testbed laboratory dedicated to process planning systems.

- Establish an on-line annotated bibliographic service connected to the Internet, dedicated to process planning publications.

- Complete a version of the Algorithm Testing System that will be suitable for production use.

MAJOR PROJECTS (Sponsor):

CMM Software Performance (Navy/Mantech)
Develop methods to evaluate the performance of software used in inspection systems.

Metal Powder Processing (STRS/Materials Science and Engineering Laboratory) Develop a controller for the Supersonic inert Gas Metal Atomization (SiGMA) process capable of regulating the production of metal powders and of using acquired knowledge to increase the efficiency of the process.

IMAR Intelligent Modules (Navy/Mantech)
Complete the development and integration of four intelligent manufacturing systems modules; transform the development of software into production software.

National Process Planning Testbed (DARPA/SISTO)
Establish a Process Planning Testbed to encourage open collaborations between process planning researchers from government, academia and industry. In the longer term, to create an open laboratory, based upon an integrating framework as defined by the process planning and standardization communities, to allow the testing and experimentation of various combinations of planning systems.

Reverse Engineering Production Cell (Navy/Mantech)
Design and implement a Reverse Engineering Production Cell capability for use in the manufacture or replacement of aircraft honeycomb sections.

STAFF:

Professional	6
Clerical Support	1

FACILITIES: AMRF Inspection Workstation
AMRF Vertical Workstation
Inspection Software Performance Facility
Supersonic inert Gas Metal Atomization (SiGMA) Facility

IMPACT:

Applications of standards, concepts and frameworks are a reliable means for the testing and evaluation needed to move standards and technology quickly into U.S. industry. By applying information technology to working systems, experience and credibility are gained that accelerate the process of dissemination and utilization of standards and supporting technology to improve U.S. competitiveness. Applications also reflect the broader mission of the Factory Automation Systems Division to apply information technology to a multi-enterprise concurrent engineering environment. Applications increase the opportunities for NIST staff to work with industry on specific processes, products and manufacturing systems.

LONG-TERM GOAL:

The long-term goal of the Life Cycle Applications Program is a set of manufacturing standards for a variety of industries that work in a multi-enterprise concurrent engineering environment. This is accomplished through the development of a complete set of applications that can access and process product data for building a complex product such as a motorized vehicle. These applications must have the functionality to process those requirements addressed by concurrent engineering methodology.

THE FACTORY AUTOMATION SYSTEMS DIVISION: AN ENGINEERING RESEARCH PARADIGM

Engineering projects traditionally have been carried out by starting with specifications, developing or adapting technology, and developing the required application. Today, the management of information--especially information in electronic form--has become a critical component of any engineering endeavor. This is especially true in the work of the Factory Automation Systems Division.

Describing the work of the Division in terms of an "Engineering Research Paradigm" is valuable for better understanding both the nature and the significance of the work. Also, the new paradigm can be used as a model for projects appropriate for NIST participation.

THE FOUR COMPONENTS OF THE PARADIGM

The paradigm consists of four components: system specification, information management technology, engineering technology, and engineering application. The paradigm is shown diagrammatically in Figure 6. The system specification component takes an industrial need such as "manufacturing world-class products" and develops the information and functional models that address the needs. The information management technology component takes the standards, in this case product and manufacturing data standards, and generates the information framework or architecture concepts required to implement an engineering application. The engineering technology component takes the functional requirements for the applications as determined by the system specification and creates the engineering framework or architecture concepts required to implement the engineering application. Finally, the engineering application component is the integration of the two technology components into a prototype application environment to test fully the proposed set of standards. The experience gained in the application environment is used to strengthen the system specification component. The outputs are indicated by the double-lined arrows: a set of standards from the system specification component and products from the engineering application component.

The following is a list of activities, technologies, and facilities in the Division for each of the four components:

System Specification

- Standards consensus
- Verification and validation testing of standards
- Conformance testing of standards
- Harmonization among product data exchange standards
- Standard for the Exchange of Product Model Data (STEP)
- Advanced manufacturing systems standards
- Enterprise integration standards
- Application protocols development

Information Management Technology

- Information modeling
- Data dictionaries
- Distributed database systems
- Persistent object data systems
- Product knowledge representations
- Communication networks
- Hypertext
- Configuration management

Engineering Technology

- Design theory, methodology and tools
- Geometric modeling
- Process and materials modeling
- Product-feature driven manufacturing processes
- Factory control and scheduling
- Manufacturing engineering software systems
- Enterprise integration modeling
- Manufacturing systems integration

Engineering Application

- Automated Manufacturing Research Facility
- Product Data Exchange using STEP (PDES)
- National PDES Testbed
- Design Research Testbed

The manufacturing engineering output that best reflects the mission and function of the Division is a shared database used for a multi-enterprise concurrent engineering environment. Research and development activities in the Division are chosen using the criterion that the result of such activities leads to the implementation of technologies and standards for supporting this database system. Such a shared database should contain an unambiguous description of the characteristics of each

manufactured product and the rules and practices needed for efficient production of quality products. The application of the elements of the Paradigm to concurrent engineering is shown in Figure 7.

ENGINEERING STANDARDS, DISCIPLINES$_1$ AND TECHNOLOGY DEVELOPMENT

The engineering standards, disciplines and technologies that have evolved to meet the challenges of manufacturing in the twenty-first century are schematically shown in Figure 8. The following discussion relates the work of the Division to the goals of enterprise integration, product data engineering, and concurrent engineering practices.

(See figures 6 & 7 and 8)

In the area of engineering standards development, the Division is building upon:

- Existing and emerging information technology standards (first introduced in the 1960's),
- Manufacturing data exchange standards (introduced in the 1970's and 1980's through such programs as the Automated Manufacturing Research Facility at NIST,
- Product data exchange standards, and
- Distributed data systems standards (introduced in the late 1980's).

The merger of these standards will lead to the development of an Enterprise Integration Framework (ElF) that will help U.S. industry to better communicate among its internal and external organizational units.

In the area of the engineering discipline required to support the standards and technology development, the Division has incorporated:

- Classic engineering disciplines (such as mechanical, electrical, civil, industrial and design) that have existed since the early 1900's,
- Electronics (introduced in the 1940's),
- Computer science (introduced in the 1960's), systems engineering (emerging in the 1970's), and
- Manufacturing engineering (introduced in the 1980's)

in an effort to promote a new engineering discipline to meet the needs of the twenty-first century. This new discipline, Product Data Engineering (PDE), is an information management technology approach to the application of standardized product data to all aspects of an enterprise's business activity.

In the area of the engineering technology research and development, the Division builds upon:

- The original "fixed industrial automation" (introduced in the early 1900's),
  - Digital computer technology (from the 1940's),
  - Information systems (from the 1960's), and
  - Flexible manufacturing systems (of the 1980's)

to develop new approaches to the application of concurrent engineering to meet U.S. industrial needs. The Division's research involves defining and implementing the information technology requirements for such manufacturing processes as product design, process planning, equipment control (e.g., machine tools, coordinate measurement machines), and logistics support (e.g., maintenance and repair). This research will lead to an better understanding of the database requirements to support the product life cycle through the development of a product data sharing technology and an enterprise integrated framework.

REFERENCES

1. Carver, Gary P. and Bloom, Howard M., "Concurrent Engineering Through Product Data Standards," NISTIR 4573, May 1991.

2. "Report of the National Critical Technologies Panel," National Critical Technologies Panel, W.D. Phillips, Office of Science and Technology Policy, Chair (1991). (Available from the National Critical Technologies Panel, 1101 Wilson Blvd., Suite 1500, Arlington, VA 22209.)